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STRATIGRAPHY OF THE DEVONIAN CHATTANOOGA AND OHIO SHALES AND EQUIVALENTS IN THE APPALACHIAN BASIN: AN EXAMPLE OF LONG-RANGE SUBSURFACE CORRELATION USING GAMMA-RAY LOGS

By

John B. Roen

1980

Prepared for

UNITED STATES DEPARTMENT OF ENERGY
Morgantown Energy Technology Center
Morgantown, West Virginia

By

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Stratigraphy of the Devonian Chattanooga and Ohio Shales and Equivalents in the Appalachian Basin: An Example of Long-Range Subsurface Correlation Using Gamma-Ray logs

BY

John B. Roen

INTRODUCTION

Previous work

The correlation of the Upper Devonian black shales in the Appalachian basin began in the mid-1800%. Early studies were concentrated on local areas rather than the whole basin. From the mid-1800% to the early 1900's, many investigators published more than one paper each, which resulted in so many contributions that it is beyond the scope of this paper to discuss adequately all the signif icant references. Accordingly, reference to previous work is of a general nature only and is not intended to be complete. For initial reference sources, the reader is referred to Cooper and others (1942) and Hass (1956).

Correlation of outcrop sections along the eastern flank of the Cincinnati arch in Ohio, Kentucky, and Tennessee was reasonably well established by C. W. Hayes, E. M. Kindle, J. S. Newberry, Edward Orton, C. S. Prosser, E. 0. Ulrich, and others by the early 1900%. Similarly during this same period, Charles Butts, Guy Campbell, N. H. Darton, A. W. Grabau, C. W. Hayes, E. M. Kindle, C. K.Swartz, Bradford Willard, H. P. Woodward, and others proposed correlations for the black shales that crop out in the Valley and Ridge province in the eastern part of the Appalachian basin from New York south to Tennessee.

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In contrast, the correlation of the Upper Devonian black shales in central and western New York was not satisfactorily resolved until the middle of this present century, largely because of a misunderstanding of facies relations and cyclic repetition of similar facies in the distal parts of the Catskill delta. Those involved in resolution of the New York black shale stratigraphy included G. H. Chadwick, K. E. Caster, Wallace de Witt, Jr., G. W. Colton, W. L. Grossman, J. F. Pepper, R. G. Sutton, and L. V. Rickard.

Until the early 1900's, studies continued on the correlations of these Upper Devonian black shales, primarily in local areas. Data to substantiate long-range correlations were not accumulated until approximately the mid-1900%. In 1942, Cooper and others published the Devonian correlation chart of North America. Late in the 1940's and 1950's, Hass (1956)suggested regional correlations based on conodonts in the Upper Devonian black shales in Virginia, Tennessee, Kentucky, Ohio, and New York. More recently, Schwietering (1970, 1979), in his study of lithologic and geophysical logs of the Devonian shales of Ohio, proposed correlations that linked the black shales of Ohio to the black shales of New York, Pennsylvania, West Virginia, and Kentucky, by extending correlations through the subsurface parts of the basin.

Purpose of report

The purpose of this paper is to confirm and extend the suggested regional correlations of Hass (1956), Schwietering (1970, 1979), and others; to propose new correlations for the black shales of Late Devonian age in the Appalachian basin; and to show the utility of the gamma-ray log for long-range correlation of subsurface stratigraphic units.

Acknowledgments

The U.S. Geological Survey (USGS) under a cooperative agreement with the U.S. Department of Energy (DOE) is charged to make a regional stratigraphic study of the Devonian black shale sequence in the Appalachian basin. Also under contract to DOE are various State geological surveys and universities. These agencies provided local stratigraphic data that were incorporated into a regional stratigraphic framework (fig. 1) for the Appalachian basin.

Appreciation is expressed to the individuals working at the State level for their fine cooperation in supplying the author with their stratigraphic information and expertise. In particular, I thank L. V. Rickard and A. M. Van Tyne of the New York Geological Survey, R. G. Piotrowski of the Pennsylvania Geological Survey, S. A. Krajewski formerly of the Pennsylvania Geological Survey, Adriaan Janssens formerly of the Ohio Geological Survey, D. G. Patchen and J. F. Schwietering of the West Virginia Geological Survey, E. N. Wilson and J. S. Zafar of the Kentucky Geological Survey, and F. R. Ettensohn of the University of Kentucky.

The writer wishes to acknowledge his colleagues; W. de Witt, Jr., R. C. Kepferle, and L. G. Wallace, all of the U.S. Geological Survey. Their assistance and advice are greatly appreciated.

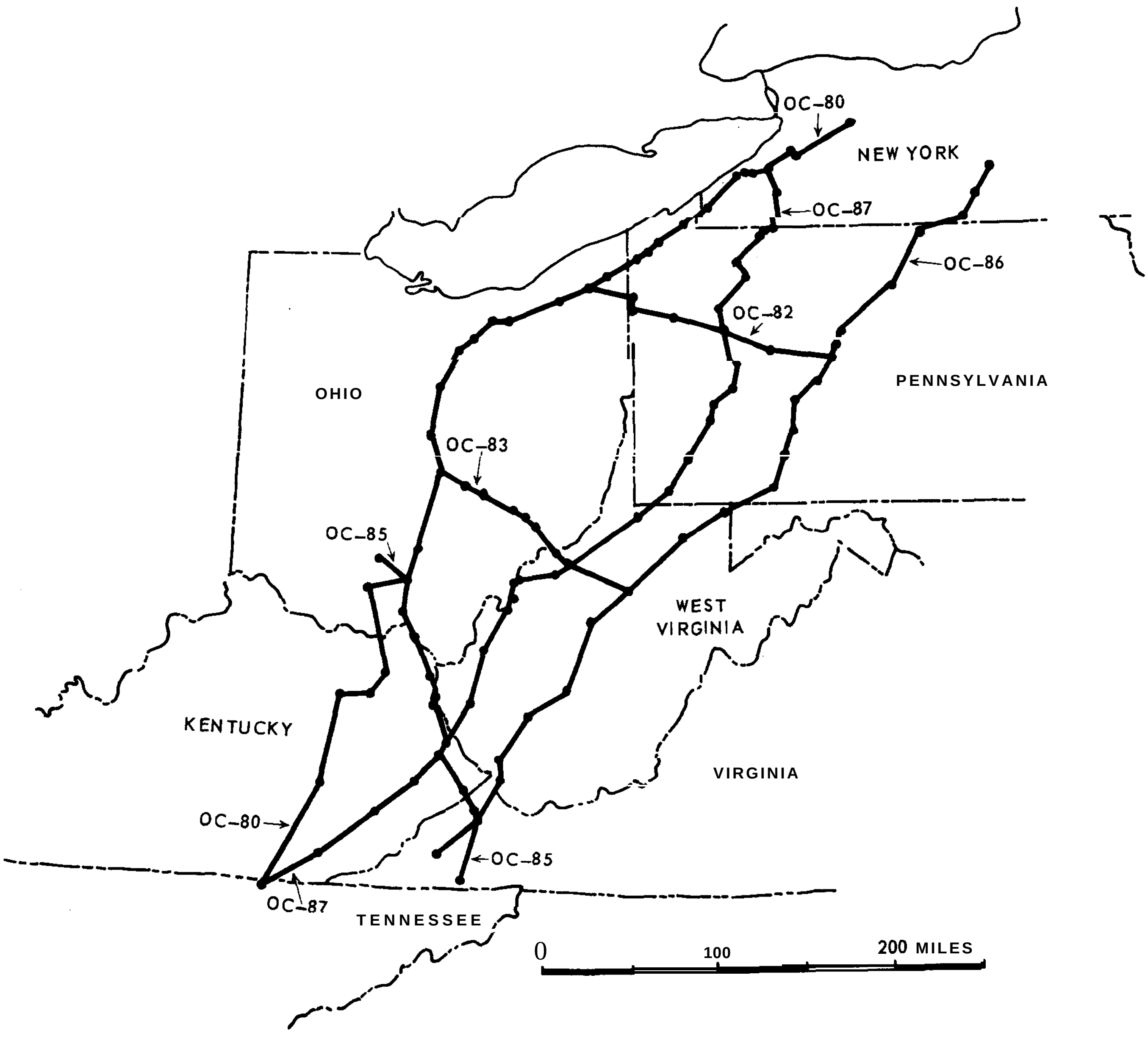

Figure 1. Map showing locations of regional gamma-ray stratigraphy cross sections in the Appalachian basin. Dots indicate location of well-log control points. See page 5 for references to published cross sections, U.S. Geological Survey Oil and Gas Investigations Charts W-80, 82, 83, and 85-87.

METHODS OF STUDY

Results here are from examination of detailed stratigraphic and paleontologic data and from the preparation of a basin-wide stratigraphic network of gamma-ray well logs and lithologic logs. The regional network was put together through the cooperation of State geological surveys and universities. These State agencies provided the USGS with one or more cross sections through their areas of responsibility. These data were then modified and compiled by the USGS into the regional network. The regional network consists of six stratigraphic sections, which have been published in the Oil and Gas Investigations Chart (OC) series of the USGS. These charts are the basis for the correlations discussed in this report, and the reader will find them a useful reference. Their size precludes inclusion in this report. The locations of the published sections are shown in figure 1. They are:

OC-80 (Wallace, Roen, and de Witt, 1977)

OC-82 (Roen, Wallace, and de Witt, 1978a)

OC-83 (Wallace, Roen, and de Witt, 1978)

OC-85 (Kepferle, Wilson, and Ettensohn, 1978)

OC-86 (West, 1978)

OC-87 (Roen, Wallace, and de Witt, 1978b)

The principal data source used in this study was gamma-ray logs from wells drilled for oil and gas. Where possible, these logs were augmented by lithologic logs to establish stratigraphic control and to show the relation between lithology and the gamma-ray log curve. The gamma-ray log reflects the concentration of the radioactive elements contained in the rock. The radioactive elements, potassium, thorium and its daughters, and uranium and its daughters, found in the mica, feldspar and other rock-forming minerals are the primary source of natural gamma radiation from rocks. Different types of rocks contain greater or lesser amounts of these radioactive elements and emit proportionate amounts of radioactivity that are recorded on the gamma-ray log. Limestone and sandstone contain lesser amounts of these elements than does gray shale and produce less response or deflection on the gamma-ray log. Shale that contains organic detritus is dark gray to black and is more radioactive than light-gray shale because the organic detritus of the darker shale traps additional uranium in the diagenetic process (J. S. Leventhal, written commun, 1979). Consequently, the dark gray to black shales produce bigger peaks than do the gray shales on the gamma-ray log. In order to differentiate uniformly these darker shales from the gray shales on the log a gray-shale base line is drawn along the peaks produced by the gray shales. Figure 2 shows the relationship betwen lithology and the gamma-ray curve and the peaks used to define the dark-shale zones. In general, shales rich in organic matter that are black (N 1), grayish black (N 2), dark gray (N 3), brownish black (5 YR 2/1), and olive black (5 Y 2/1) produce a high response or positive deflection on the gamma-ray trace (color code from Goddard and others, 1948).

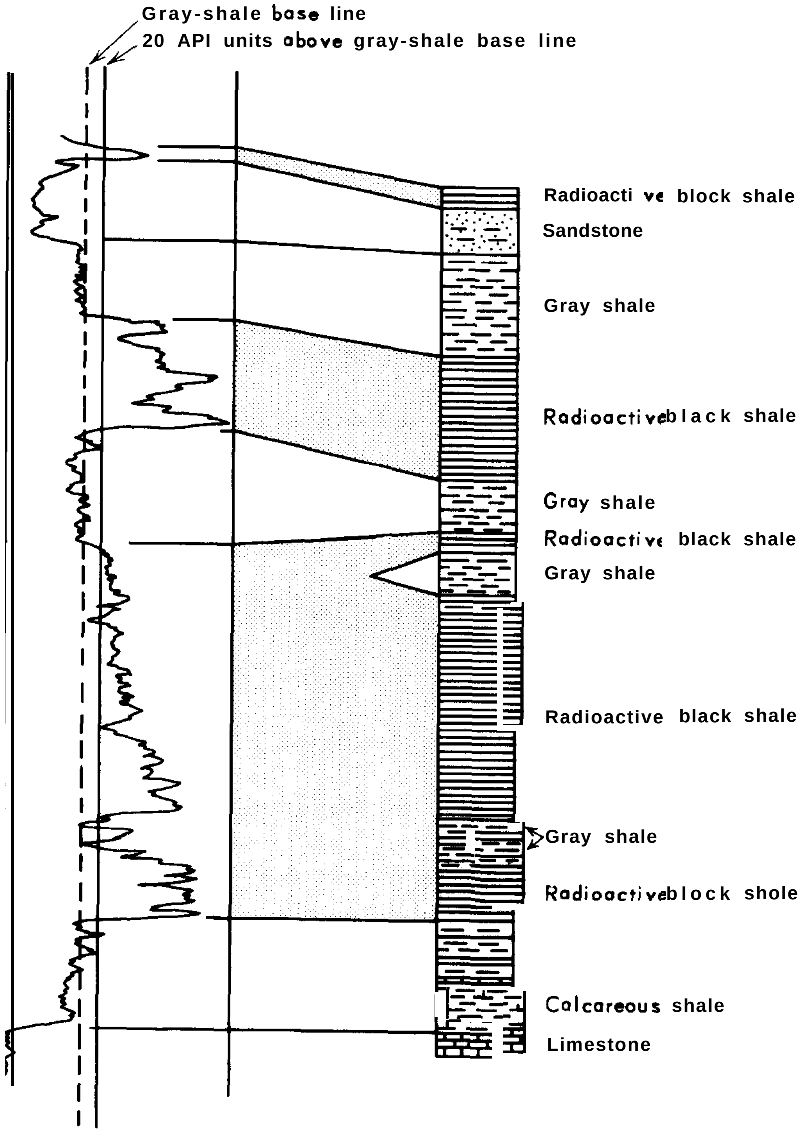

Figure 2. Comparison of a gamma-ray log and a lithologic log showing the relationship of the log response to various types of rock. API, American Petroleum Institute.

For the most part, the correlations made in the preparation of the six stratigraphic sections were based on the regional continuity of the radioactive dark shales that produced a deflection greater than 20 API (American Petroleum Institute) units above the gray-shale base line (fig. 2), and on the similarity of configuration of radioactive peaks on the log traces.

Figure 3 illustrates the utility of the gamma-ray log for establishing regional subsurface correlations across a long distance within the Appalachian basin. The section (shown in fig. 3) extends 400 miles from Kentucky through Ohio and northern Pennsylvania into New York. It was abstracted from the 600 mile-long section, OC-80 (Wallace, Roen, and de Witt, 1977) (fig.' 1); and clearly shows the long-range continuity of characteristically similar log traces of a sequence of radioactive black shale and less radioactive rocks. Note the log-trace characteristics of the Rinestreet, Pipe Creek, and Dunkirk interval from New York to Kentucky. In particular, notice the double peak of the Pipe Creek signature and its relation to the strong peak in the basal part of the younger Dunkirk. These characteristic signatures provided confirmation of correlations previously suggested and allowed the establishment of new correlations of black shale stratigraphic units across about 700 miles in the Appalachian basin.

The correlations suggested in this study are based primarily on the radioactive response of the black-shale units recorded on the gamma-ray log. The area of study, and the resulting areal extent of the units discussed here, unless otherwise noted, is limited by the stratigraphic network shown in figure 1.

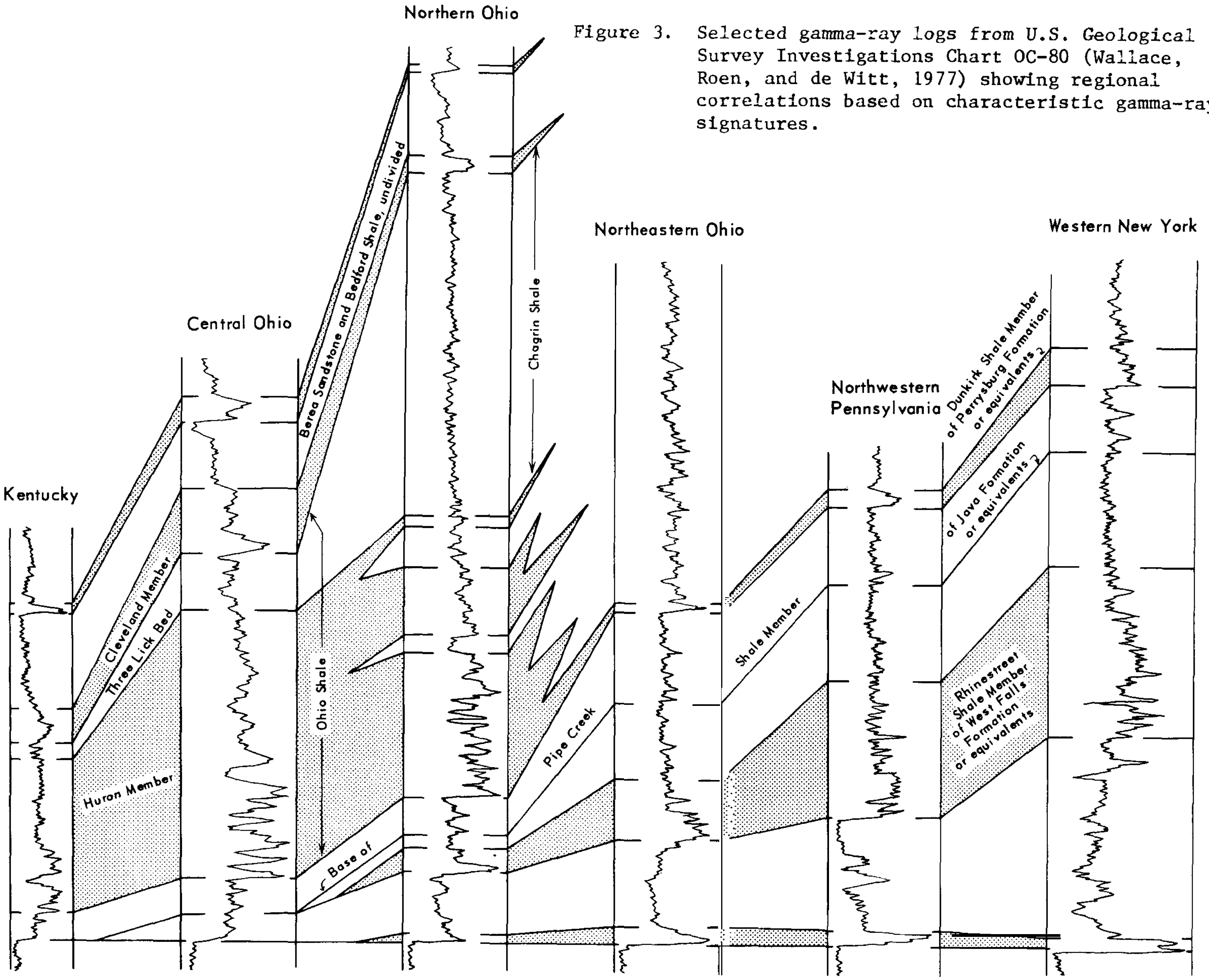

Figure 3. Selected gamma-ray logs from U.S. Geological Survey Investigations Chart OC-80 (Wallace, Roen, and de Witt, 1977) showing regional correlations based on characteristic gamma-ray signatures.

STRATIGRAPHY

The Ohio Shale as recognized in Ohio is divided into two members; the Cleveland Member in the upper part and the Huron Member in the lower part. In north central Ohio, the Cleveland Member is underlain by the Chagrin Shale and overlain by the Bedford Shale. From central Ohio, northeast along OC-80 (Wallace, Roen, and de Witt, 1977) (fig. 1), the Cleveland can be recognized to a point adjacent to the Ohio-Pennsylvania line. Eastward from this point, the unit cannot be differentiated either in surface exposures or on the gamma-ray logs from the enclosing Bedford and Chagrin Shales. It is not recognized on OC-82 (Roen, Wallace, and de Witt, 1978a) (fig. 1). Southward along OC-80 (Wallace, Roen, and de Witt, 1977), the Cleveland correlates with the upper unit of the Gassaway Member of the Chattanooga Shale (fig. 7). According to Provo, Kepferle, and Potter (1977) the middle unit of the Gassaway is equivalent to the Three Lick Bed of the Ohio Shale of eastern Kentucky. The stratigraphic relations shown on the western section, OC-80 (Wallace, Roen, and de Witt, 1977) suggest that Three Lick Bed is the thin, distal part of the Chagrin Shale which underlies the Cleveland Member and separates it from the Huron Member of the Ohio Shale.

The physical stratigraphy demonstrated here confirms the opinion of Hass (1956, p. 23) that "The conodont fauna of the youngest beds of the Gassaway is like that in the upper part [Cleveland Member] of the Ohio shale of Ohio and Kentucky...." The correlation of the upper unit of the Gassaway Member with the Cleveland Member is also supported by the studies of Conant and Swanson

(1961, p. 20). They based their correlation on a distinctive Spathognathodus inornatus (Branson and Mull) conodont fauna.

The Cleveland-upper unit of the Gassaway beds were traced into southwestern Virginia. Kepferle and others (in press), used surface gamma-ray profiles and data from the Oil and Gas Charts referred to here to correlate the Cleveland Member with the lower part, units 3 to 8, of the Big Stone Gap Member of the Chattanooga Shale of Roen and others (1964). T. W. Huddle (in Roen and others, 1964, p. B47) identified a Late Devonian conodont fauna containing Spathognathodus inornatus (Branson and Mull) from units 3, 4, and 5 of the lower part of the Big Stone Gap Member. The fauna supports the lithologic correlation of the lower black shale beds of the Big Stone Gap Member of Wise County, Virginia, with the upper unit of the Gassaway Member of the Chattanooga Shale in central and eastern Tennessee and the Cleveland Member of the Ohio Shale in Ohio and eastern Kentucky.

The areal extent and the regional correlation of the Cleveland and its equivalents are shown in figures 4, 5, and 6. The extent of the Gassaway Member (Conant and Swanson, 1961; Glover, 1959) suggests that the Cleveland, equivalent the upper unit of the Gassaway, may exist to the south into Alabama and Georgia.

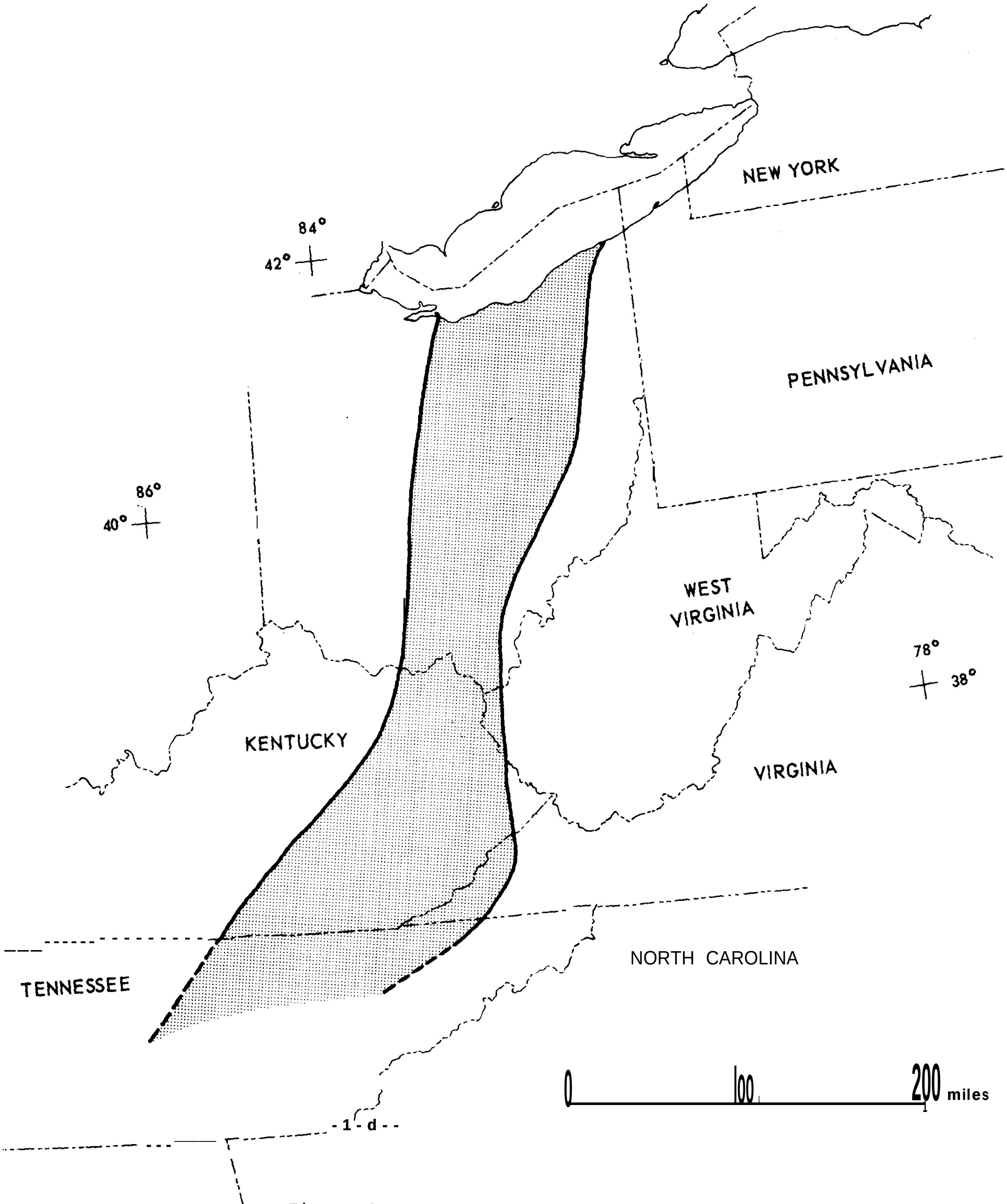

Figure 4. Map showing area1 extent of the Cleveland Member of the Ohio Shale and its equivalent, the upper unit of the Gassaway Member of the Chattanooga Shale.

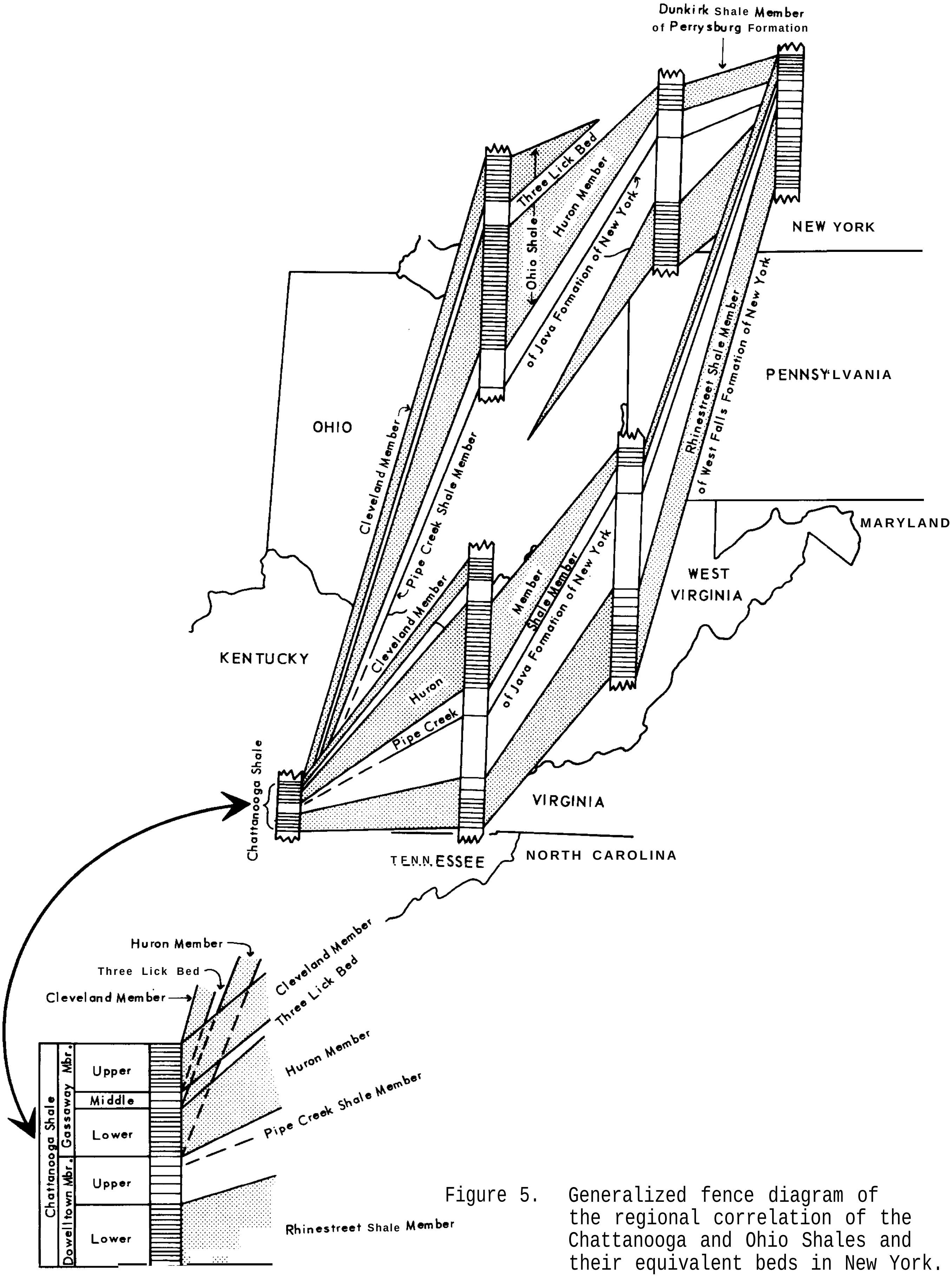

Figure 5. Generalized fence diagram of the regional correlation of the Chattanooga and Ohio Shales and their equivalent beds in New York.

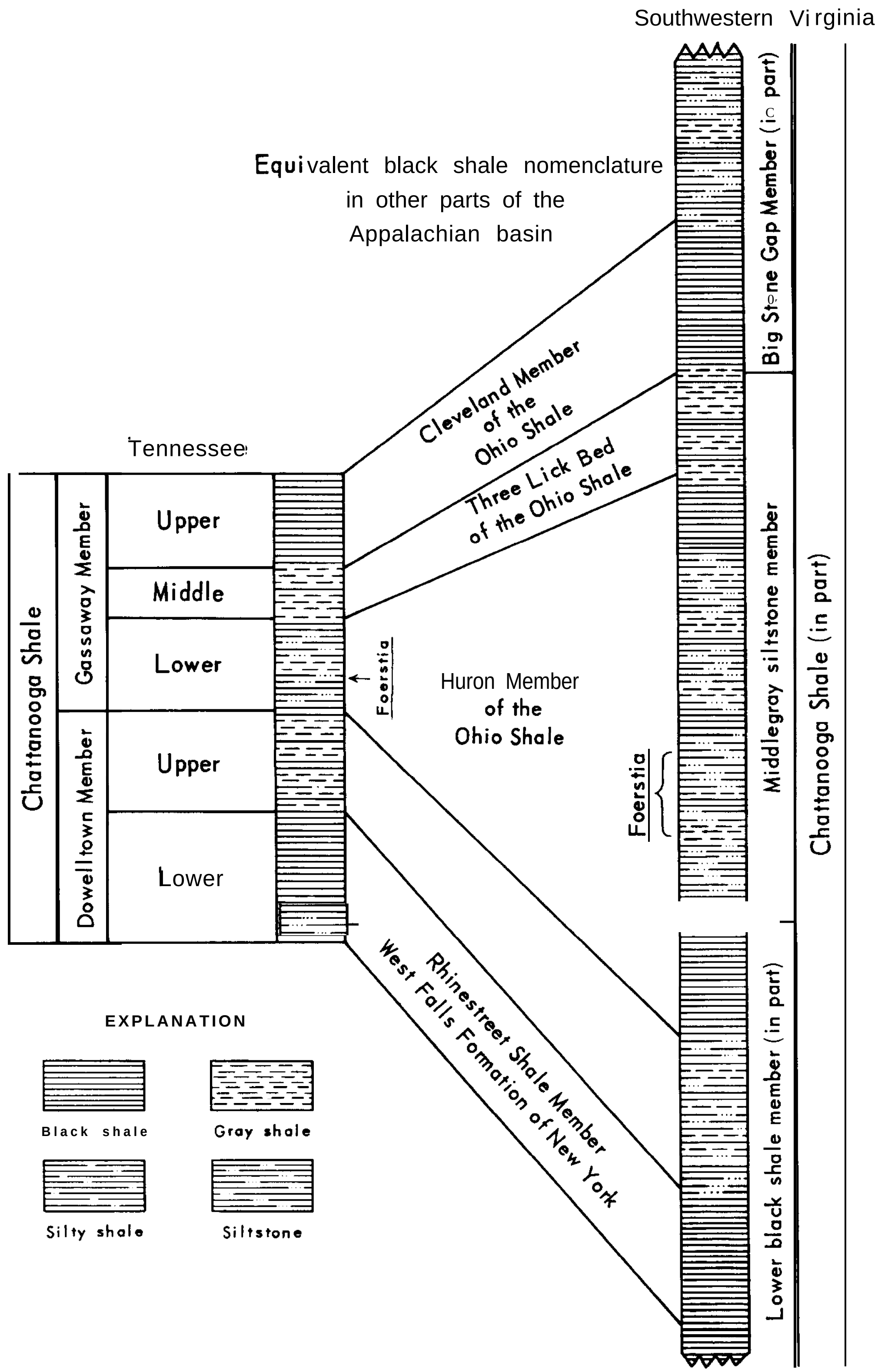

Figure 6. Generalized diagram showing the correlation and nomenclature of the Upper Devonian black shales in Tennessee and southwestern Virginia. Not to scale.

The radioactive black shale of the Huron Member of the Ohio Shale can be traced (on OC-80, Wallace, Roen, and de Witt, 1977) (fig. 1) from north central Ohio into eastern Ohio where it is divided into a lower and upper part as it intertongues with the Chagrin Shale. The upper part of the Huron thins to extinction in Ashtabula County, northeastern Ohio. Although the lower part also thins eastward, it can be traced across northwestern Pennsylvania into western and central New York where it is the Dunkirk Shale Member of the Perrysburg Formation (fig. 5). This correlation supports that of Schwietering (1970, p. 33).

Similarly the radioactive black shale of the Huron thins from central Ohio southeastward toward central West Virginia (OC-83, Wallace, Roen, and de Witt, 1978). The upper part of the member grades into gray shale in southeastern Ohio, whereas the eastward-thinning lower part of the Huron extends into central West Virginia. Only the basal beds are present in central West Virginia and are equivalent to the Dunkirk of New York.

The tongue of Chagrin Shale separating the upper and lower parts of the Huron thins south and west from northeastern Ohio. The upper and lower parts of the Huron appear to merge to the west, and the entire sequence thins southward into Kentucky and northern Tennessee. The position of the Huron relative to'the overlying Three Lick Bed on the gamma-ray logs (Roen, Wallace, and de Witt, 1978b) and the correlative evidence presented here for units above and below the Huron Member of the Ohio Shale suggest that the Huron is mainly correlative with the lower unit of the Gassaway Member of the Chattanooga Shale of Tennessee (fig. 5).

The extent of the Huron-Dunkirk beds as shown in OC 80, 85, and 86 and as described by Kepferle and others (in press) indicates that these beds, as well as beds equivalent to the Three Lick Bed, are present in southwestern Virginia. In the Big Stone Gap area, Wise County, Virginia, the Huron Member of the Ohio Shale and its equivalents are represented by parts of the middle gray siltstone member and the lower black-shale member of the Chattanooga of Roen and others (1964) and Miller (1965). This relationship is substantiated by the presence of the stratigraphically restricted fossil algae Foerstia within the sequence.

In Ohio, the Foerstia zone is within the Huron Member of the Ohio Shale (Hass, 1956, p. 21; Schopf and Schwietering, 1970). The Foerstia zone is found below the Three Lick Bed when the bed is present. The Three Lick Bed is equivalent to the middle unit of the Gassaway and separates the Gassaway into an upper and lower unit. Consequently, the Foerstia zone is in the lower unit of the Gassaway Member of the Chattanooga Shale and equivalent beds.

The Foerstia zone has been reported by Hass (1956, p.21) at his localities 225 and 228 in southeastern Tennessee. Recently, Kepferle and Roen recovered previously unreported Foerstia from Hass' (1956, pl 1) locality 220 in southeastern Tennessee. Additional localities have been found by Roen, Milicis and others (in press) and Roen, Milici, and Wallace (in press), extending the geographic range of Foerstia throughout eastern Tennessee to southwestern Virginia (Kepferle, Roen, and Wallace, unpublished data). Foerstia was found at the Big Stone Gap section, Virginia, by Kepferle and others (in press) in beds thought by this author to represent an expanded sequence of the lower unit of the Gassaway. The areal extent and the correlation of the Huron Member and its equivalents are shown on figures 5, 7, and 8.

The black shale of the Rhinestreet Shale Member of the West Falls Formation is a recognizable unit in the subsurface of western and central New York. By use of gamma-ray logs and a few lithologic sections, this black-shale unit was traced across western Pennsylvania into the eastern half of Ohio where it thins to extinction against an unconformity. The Rhinestreet could not be traced continuously southward on the stratigraphic network (fig. 1) because it is not present along the western cross section (OC-80, fig. 1) in Ohio, Kentucky, and Tennessee. However, the Rhinestreet's characteristic gamma-ray signature in conjunction with the Huron-Dunkirk and Pipe Creek signatures (see fig. 3), indicates that the black Rhinestreet equivalent is present in the area shown in OC-87 (Roen, Wallace, and de Witt, 1978b) and OC-85 (Kepferle, Wilson, and Ettensohn, 1978) as far south as southwestern Virginia and northeastern Tennessee. In Tennessee, the Rhinestreet correlates with the lower unit of the Dowelltown Member of the Chattanooga Shale of Conant and Swanson (1961, p. 24).

In the Tidewater-Wolf's Head Smith No. 1 well in Scott County, Virginia, (OC-85), the Rh'mestreet-equivalent beds are a sequence of black to very dark gray shale whose base is approximately 30 feet above the Wildcat Valley Sandstone. The Rhinestreet-equivalent beds of the Tidewater-Wolf's Head well were correlated by Wallace de Witt, Jr., and Roen to a sequence of black shale in the section measured by Dennison and Boucot (1974) at Little War Gap, Tennessee. To confirm the 600-mile, gamma-ray log correlation of the Rhinestreet from central New York to Tennessee and Virignia, R. C. Kepferle collected conodonts about 25 feet above the base of de Witt and Roen's Rhinestreet-equivalent beds, which overlie the Wildcat Valley Sandstone at Little War Gap.

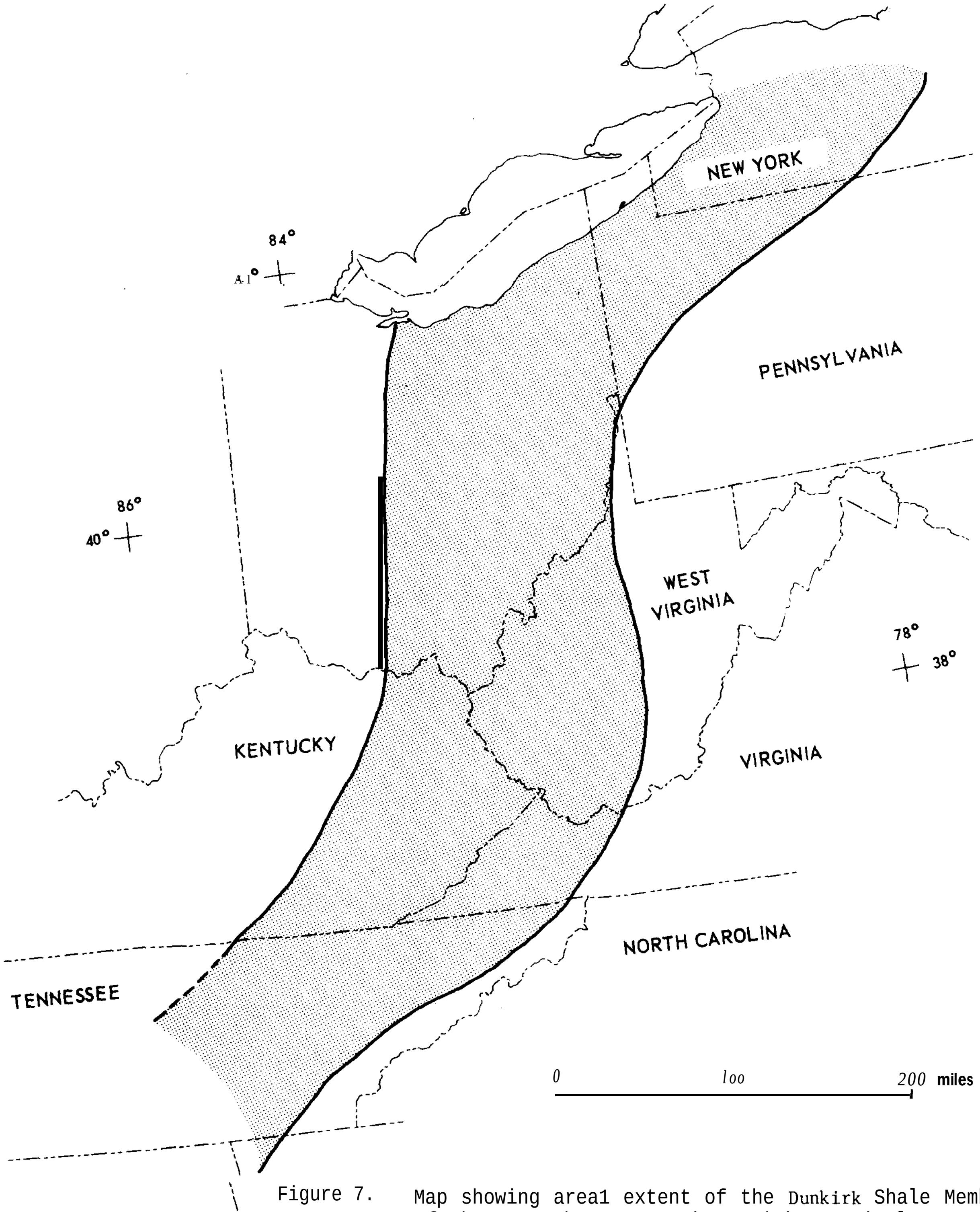

Figure 7. Map showing areal extent of the Dunkirk Shale Member of the Perrysburg Formation and its equivalents, the Huron Member of the Ohio Shale and the lower unit of the Gassaway Member of the Chattanooga Shale.

Conodonts from Kepferle's collections were examined by Anita Harris of the USGS. She identified Palmatolepis punctata, a Late Devonian form reported in New York from the upper part of the Cashaqua Shale Member of the Sonyea Formation and the Rhinestreet Shale Member of the West Falls Formation. Harris' Late Devonian age assignment of the black shale confirms 1) the extension of the Rhinestreet equivalent into Virginia and northeastern Tennessee, and 2) the fact that the Rhinestreet is equivalent to the lower unit of the Dowelltown Member of the Chattanooga Shale of Late Devonian age (figs. 5 and 6). The areal extent of the Rhinestreet and its equivalents is shown on figure 8.

The correlation of the Rhinestreet with the lower unit of the Dowelltown Member of the Chattanooga and the thinning to near extinction of the beds between the Rhinestreet and the younger Huron-Dunkirk facies further substantiate the correlation of the Huron-Dunkirk beds with the lower unit of the Gassaway Member of the Chattanooga Shale.

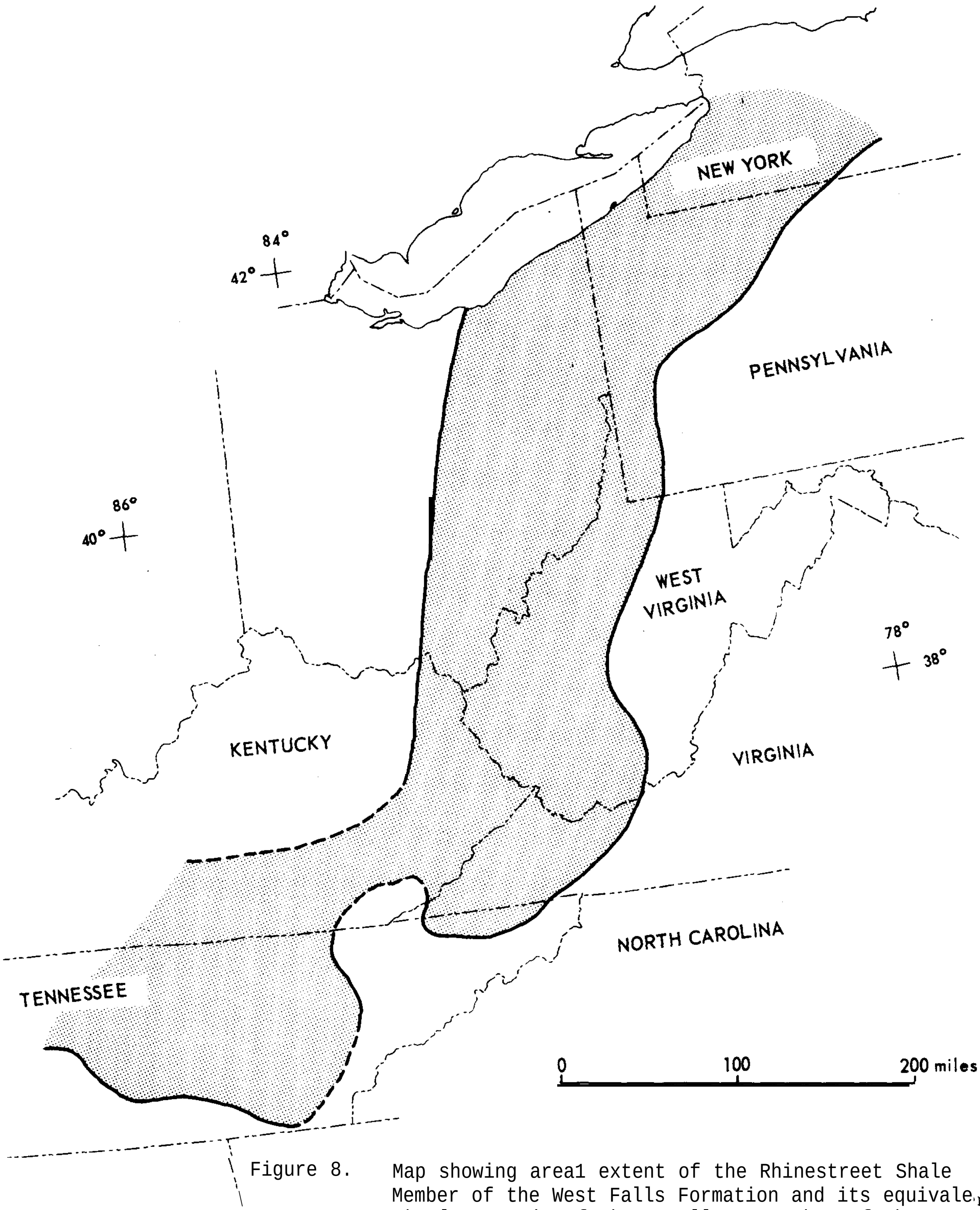

Figure 8. Map showing areal extent of the Rhinestreet Shale Member of the West Falls Formation and its equivalents, the lower unit of the Dowelltown Member of the Chattanooga shale and the lower part of the lower black shale member of the Chattanooga of southwestern Virginia.

CONCLUSION

The Cleveland Member of the Ohio Shale is equivalent to the upper unit of the Gassaway Member of the Chattanooga Shale of Tennessee. The Three Lick Bed of the Ohio Shale (Provo, Kepferle, and Potter, 1977), which correlates with the middle unit of the Gassaway, is a distal part of the Chagrin Shale. The Huron Member of the Ohio Shale is the lower unit of the Gassaway Member of the Chattanooga Shale of Tennessee. The lower part of the Huron thins eastward and is equivalent to the Dunkirk Shale Member of the Perrysburg Formation of New York.

In southwestern Virginia, the beds of the Cleveland and the upper unit of the Gassaway are represented by the lowermost black-shale sequence in the Big Stone Gap Member of the Chattanooga Shale. The Huron-Dunkirk bed and the lower unit of the Gassaway are equivalent to the highly radioactive black shale included in the middle gray siltstone member and the upper part of the lower black shale member of the Chattanooga Shale southwestern Virginia .

The Upper Devonian Rhinestreet Shale Member equivalents of the West Falls Formation of New York are extended into Pennsylvania, Ohio, Kentucky, West Virginia, Virginia, and Tennessee. In Tennessee, the Rhinestreet correlates with the lower unit of the Dowelltown Member of the Chattanooga Shale. Locally in southwestern Virginia the Rhinestreet correlates, except for a very few feet at the base, with the radioactive lower part of the lower black shale member of the Chattanooga Shale.

The correlations discussed here demonstrate the utility of the gamma-ray log for regional, basinwide stratigraphic studies. Through the use of these logs, suggested correlations based on paleontologic evidence (Hass, 1956) were confirmed and new correlations were established in the Appalachian basin across at least 700 miles. These logs used in conjunction with a few lithologic logs and gamma-ray profiles of surface sections (Ettensohn and others, 1979) have proven to be a useful tool for long-range stratigraphic studies.

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